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14. ABSTRACT In comparison to our existing melt compounding, the requested twin screw extruders have a number of benefits: (1) continuous processing with high consistency, (2) high processing productivity, (3) remarkable mixing quality, (4) high flexibility of screw design, thus (5) can meet specific requirements for a wide range of polymers and composites. Particularly, because of the similarity between twin screw extruder and industrial manufacturing, the twin screw extruder will provide greater potential to translate the lab research to industrial manufacturing process. <del>First, the high productivity and remarkable mixing quality of the twin screw extruders will significantly enhance the</del>					
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## Report Title

Request Twin Screw Extruder to Enhance DoD Interested Polymer Nanocomposite Research and STEM Program

### ABSTRACT

In comparison to our existing melt compounding, the requested twin screw extruders have a number of benefits: (1) continuous processing with high consistency, (2) high processing productivity, (3) remarkable mixing quality, (4) high flexibility of screw design, thus (5) can meet specific requirements for a wide range of polymers and composites. Particularly, because of the similarity between twin screw extruder and industrial manufacturing, the twin screw extruder will provide greater potential to translate the lab research to industrial manufacturing process. First, the high productivity and remarkable mixing quality of the twin screw extruders will significantly enhance the polymer nanocomposite research such as anti-scratch coating, high k materials and tissue engineering. Second, the flexibility of twin screw will strengthen the collaborations between PI and other faculty members thus will enhance the interdisciplinary research throughout the entire University. Third, the new equipment will enhance the University's STEM program by providing them more research opportunities with multidisciplinary training, which can significantly enhance the education and STEM programs for African American students, thus will provide more African American STEM workforces to the nation.

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**Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:**

**(a) Papers published in peer-reviewed journals (N/A for none)**

<u>Received</u>	<u>Paper</u>
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**TOTAL:**

**Number of Papers published in peer-reviewed journals:**

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**(b) Papers published in non-peer-reviewed journals (N/A for none)**

<u>Received</u>	<u>Paper</u>
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**TOTAL:**

**Number of Papers published in non peer-reviewed journals:**

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**(c) Presentations**

Number of Presentations: 0.00

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**Non Peer-Reviewed Conference Proceeding publications (other than abstracts):**

Received      Paper

**TOTAL:**

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

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**Peer-Reviewed Conference Proceeding publications (other than abstracts):**

Received      Paper

**TOTAL:**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

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**(d) Manuscripts**

Received      Paper

**TOTAL:**

Number of Manuscripts:

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**Books**

Received      Book

**TOTAL:**

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

### Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: ..... 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense ..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: ..... 0.00

### Names of Personnel receiving masters degrees

NAME

**Total Number:**

### Names of personnel receiving PHDs

NAME

**Total Number:**

### Names of other research staff

NAME

PERCENT SUPPORTED

**FTE Equivalent:**

**Total Number:**

### Sub Contractors (DD882)

### Inventions (DD882)

## Scientific Progress

The new equipment obtained through this award (US ARMY Grant: W911NF-15-1-0051) has significantly strengthened the research capabilities at Howard University and also significantly enhanced students training on STEM areas.

(I) The new obtained equipment through this award has significantly strengthened the research capabilities at Howard University by providing new technique for polymer nanocomposite processing, developing new research projects, and leading to a number of research outcomes.

First, the new obtained twin-screw extruder provided new technique for polymer nanocomposite processing, while we have melting compounding machine in this lab. The remarkable mixing capability of the new equipment has added significant value to our existing processing units. This new twin screw extruder has remarkable mixing capability, due to the interpenetration of the screws, leading to the extent of shearing/mixing to be precisely adjusted. The twin-screw extruder also improved the composite processing consistency. In comparison to our existing melt compounding, the continuous extrusion of twin screw leads to consistency in production and better control of product quality.

In comparison to our existing melting compounding unit, this new twin-screw extruder provided us the greater productivity due to the continuous operation together with the excellent mixing effect. In addition, twin-screw extruder is better for medium or large-scale production because it can provide a continuous compounding process. Due to the continuous processing feature, twin-screw extrusion could fabricate polymer nanocomposite on the kilogram level and could possibly process homogeneous composite with consistent quality up to 10 kg/hour, which is certainly helpful for the scaling up for industrial manufacturing in the future. Particularly, because twin screw extrusion has become popular in industries, the obtained twin screw extruder in this lab can benefit to future research at Howard University on the following two aspects: providing greater potential to translate the lab research to industrial manufacturing process; providing students education and training on manufacturing process similar to industry manufacturing.

Second, the new equipment has significantly enhanced the overall research capabilities at Howard University: The Wang Lab at Howard University focuses on development of polymer nanocomposite and bio-inspired materials. The research projects in this lab include polymer/carbon nanocomposites, polymer/calcium phosphate composites, and etc, which are within the technical fields of interest to the DoD "Materials Division". In order to conduct the above multidisciplinary research projects, Wang lab already has a number of existing equipment, including Haake PolyLab OS 16, Rheomix 600 melt compounding and MiniJet II inject molding for composite fabrication/processing, and TA-Q50 TGA, TA-Q800 DMA, Zeiss Auriga FIB-SEM, PL-50 GPC, and PE 8000 DSC for properties evaluation/testing. Particularly, Haake PolyLab OS 16, Rheomix 600 melt compounding and MiniJet II inject molding have provided basic equipment for polymer nanocomposite processing and molding. However, the melt compounding mixer is only suitable for small-scale formulation research.

The twin-screw extruder obtained through this award is better for medium to large-scale production because it can provide a continuous compounding process. Specifically, the new twin screw extruders obtained through this award enhance the research at Howard on the following multiple aspects: (1) continuous processing with high consistency, (2) high processing productivity, (3) remarkable mixing quality, (4) high flexibility of screw design, thus (5) can meet specific requirements for a wide range of polymers and composites. Particularly, because of the similarity between twin-screw extruder and industrial manufacturing, the twin-screw extruder provides us greater potential to translate the lab research to industrial manufacturing process.

Third, the obtained equipment created opportunities to develop 3 new research projects, which are within technical fields of interest to the DoD. The new twin screw has strengthened the interdisciplinary collaborations between PI and other faculty members, both on existing collaborative projects and developing new collaborative projects. The high productivity and remarkable mixing quality of the twin screw extruders has significantly enhanced the polymer nanocomposite research such as polymer/carbon composites, polymer/calcium phosphate composites, polymer/MgO nanocomposites, anti-scratch coating, high k materials and tissue engineering.

The significant features of the twin-screw extruder are the great flexibility, which allows twin screw extruder to meet specific requirements for many kinds of polymer and blends. The polymer systems including plastics and modified plastics including polyester, nylon, polyolefin, polystyrene, polyurea, polyurethane, polyamide (e.g. Kalvar), polycarbonate, and textured products, cellulose pulps, etc. Therefore, this twin-screw extruder not only strengthened existing research capabilities, but also provided additional opportunities to develop more kinds of polymer composites for DoD application.

A typical example for the development new research project is the fabrication of polymer carbon nanotube composite (CNT). Based on the new equipment, two faculty members, Dr. Wang and Dr. Harris developed a new research project, in which a feasible route was developed to fabricate an electroactive and biocompatible micro-patterned Single-walled carbon nanotube/poly(3,4-ethylenedioxythiophene) composite films (SWNT/PEDOT) for electrodes. The uniform SWNT/PEDOT composite films with nanoscale pores and microscale grooves significantly enlarged the electrode-electrolyte interface, greatly improved the stability of the SWNT/PEDOT composite film and decreased the electrode/electrolyte interfacial impedance. This new project may lead to new technology for nerve injuries, which could benefit the soldier injuries in battlefield. Partial results of

this new project have been published on Colloids and Surfaces B: Biointerfaces 145 (2016) 768–776.

In addition to the above new project, Dr. Wang and Dr. Mitchell also collaboratively developed another new project on polymer magnesium nanocomposite. Recently, we developed polylactide/calcium phosphate composite from various calcium phosphate filler such as tetracalcium phosphate, tricalcium phosphate, which could be one candidate as the bioresorbable materials for bone repair and tissue engineering. While the mechanical strength can be improved by the interfacial modification, the resorption rate was relatively long regarding the new bone regeneration. In the new project, MgO nanoparticle was also incorporated within the PLA/CaP system. Due to the basic property of MgO, it was hypothesized to accelerate the acidic degradation PLA and may also neutralize the acidic lactic product, so that the inflammation effect from lactic acid may be reduced. This new project was going on and the related results might be published by the end of 2016. In this new project, the new obtained twin screw extruder is critical, because it provided remarkable mixing effect for the three phases PLA/CaP/MgO composite system.

(II) The new twin-screw extruder obtained through this award strengthened the collaboration between faculty members at Howard University and led to a number of research outcomes. Based on the new equipment, Dr. Wang has established successful collaboration between a number of faculty members, e.g. Dr. Harris, Dr. Mitchell, Dr. Anderson and Dr. Gu. This new equipment certainly accelerated the research productivity, entirely or partially. Even within only one period, the related results from this new equipment have led to three manuscripts. Two of them have been published and one is under review. The related manuscripts are attached and are listed below:

1. X Hui, L Qian, G Harris, T Wang\*, J Che.\* Fast fabrication of NiO@Graphene Composites for Supercapacitor Electrodes: Combination of Reduction and Deposition. Materials Design (109) 2016, 242-250.
2. X Shi, Y Xiao, H Xiao, G Harris, T Wang,\* J Che.\* Topographic guidance based on microgrooved electroactive composite films for neural interface. Colloids and Surfaces B: Biointerfaces 145 (2016) 768–776.
3. Y Xiao, T Wang\*, X Chen, X Yang\*, J Mitchell. Nitrogen-doped graphene combined with bioactive conducting polymer: an ideal platform for neural interface. under review.

(III) The new twin screw extruder obtained through this award significantly enhanced the research related education and STEM Programs at Howard University:

As one top Historically Black College/University, Howard University has played a key role to broaden participation in the nation's STEM workforce (Science, Technology, Engineering and Mathematics) (STEM), particularly from African American students. As the return from this award, this lab has trained total 9 students/postdocs. All of the 9 trained students are minority, 6 out of the 9 students are African American and 3 of the 9 students are Asian.

No	Students	Race	Degree Level	Training
1.	M Abdelrahim	African American	Graduate	Hand-on Operation
2.	D Courts	African American	Undergraduate	Hand-on Operation
3.	J Che	Asian	Ph.D.	Hand-on Operation
4.	T Etes	African American	Undergraduate	Visit Equipment
5.	H Liu	Asian	Ph.D.	Hand-on Operation
6.	P Losier	African American	Undergraduate	Visit Equipment
7.	G Oyegbola	African American	Undergraduate	Visit Equipment
8.	K Robison	African American	Undergraduate	Visit Equipment
9.	Y Xiao	Asian	Ph.D.	Hand-on Operation

First, the new twin screw extruder obtained through this award not only has provided students more consolidated research training on the research related to polymer nanocomposite fabrication, but also provided opportunities to more students to expose to the state-of-the-art facilities, thus significantly enhanced the potential to attract more students to pursue degrees in this interdisciplinary STEM area.

Second, the new equipment provided students more training opportunities on interdisciplinary research projects. The twin-screw extruder combined with our existing PolyLab system has provided students working within multidisciplinary research areas from nanomaterials preparation, polymer coating, composite fabrication, and properties evaluation. 5 students or Postdocs have been trained to operate the new twin-screw extruder (see table above).

Third, in addition to the students from this single lab, the students from other labs also have the opportunity to visit/watch the new equipment, thus the new equipment may initiate students on STEM throughout university. 4 more undergraduate students have visited the new equipment and gained primary information for polymer nanocomposite fabrication (see table above). This experience could provide students a basic knowledge for polymer composite fabrication, which may initiate their interest to STEM areas and certainly increased students' interest to pursue degrees in STEM areas. Given the Howard University's substantial and unprecedented history of educating, training, and mentoring underrepresented groups, the enhanced research capabilities and education opportunities from this requested twin screw extruder will certainly significantly contribute to the



nation’s STEM program in the future.

**Technology Transfer**